Advanced HELLER System To Improve Economics of Power Generation

by

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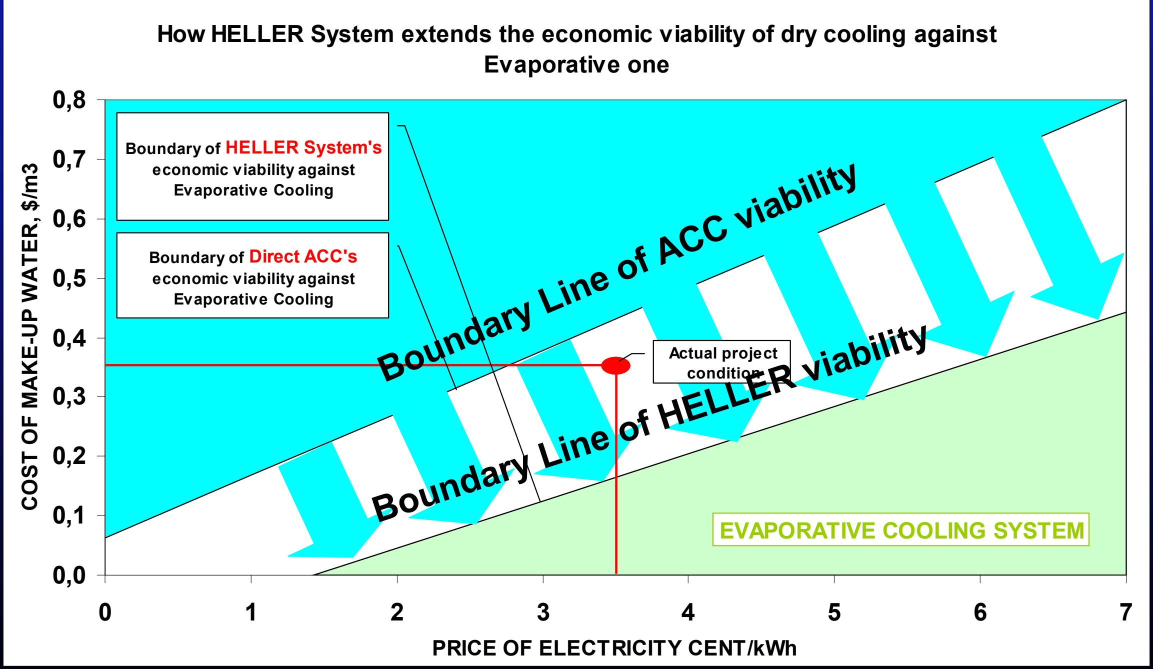
Paper for EPRI Conference on
„Advanced Cooling Strategies/Technologies",
June 2005, Sacramento (CA)

Contents

1. Summary Statements & Conclusions

- A more adapting economic climate (driven by shrinking fresh water resources and growing environmental awareness) combined with a steady technical development have been positioning HELLER System to offer improved economics and reduced environmental impact for thermal power plants.
- Results of comprehensive present value based life cycle analyses suggest, that application of a natural draft HELLER System can be justifiable purely on economic basis against a wet cooling system even at a medium cooling water make-up cost – thus providing the environmental advantages as an extra benefit.
- The state-of-the-art HELLER System can significantly extend the economic viability of dry cooling against conventional wet cooling solutions.



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2. How to Evaluate Cooling Systems' Economics

- **Case studies on comparative basis**

  - The economic evaluation of HELLER System is introduced by results of case studies investigating the application for:

    - an 800 MW_e coal fired supercritical power plant - presented in details
    - a 500 MW_e combined cycle power plant (CCPP) – only summary
    - an 800 MW_e CCPP – only summary

  - To provide practical basis for judgment, the analysis is a comparative one considering besides the HELLER-type Dry Cooling System also the Evaporative Cooling System (the mainstream power cooling solution) and the Direct ACC (another proven dry cooling).

  - Cooling systems are sized to serve the same power cycle (i.e. having the same heat input), however different LP turbine exhaust annulus area and last stage blading are considered for dry cooled units and for evaporative one.

- **Cooling system as a whole and as integral part of the power cycle**

  - The cooling system is regarded as an integral part of the power cycle, therefore its impact on the costs of the complete power plant is investigated.

  - The complete cooling system (from the turbine exhaust flange on) and all kinds of its costs are considered together with those indirect costs or gains, which occur at other parts of the power plant, however are attributable to the application of the selected cooling system.

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2. How to Evaluate Cooling Systems' Economics – cont.

- **Present value based economic life-cycle analysis**

The present value (PV) based economic life-cycle cost analysis represents an effective method for a comprehensive evaluation:

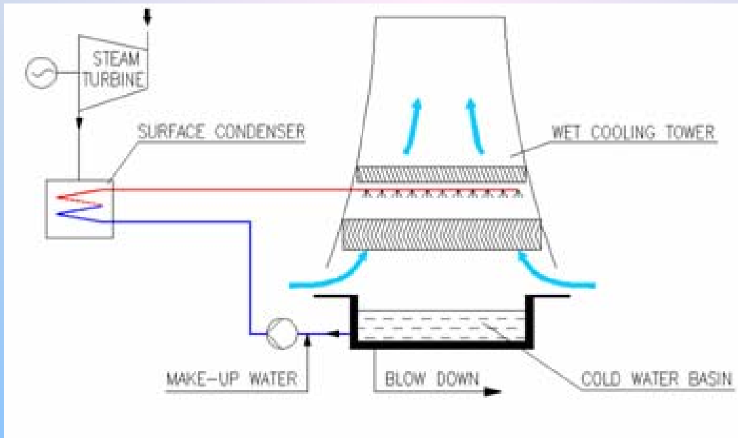
PV = I + (Pp+Pw+Pm+Pu) / A, where

- **I** (\$) total cooling system-related investment costs
- **Pp** (\$ / year) = Pt+Pa, the annual costs / gains calculated from the differences of net electricity production, where:
  - » **Pt** (\$ / year) costs of turbine cold-end yearly power loss due to the impact of ambient temperature variation on turbine back- pressure
  - » **Pa** (\$ / year) cost of annual cooling system auxiliary power consumption
- **Pw** (\$ / year) cost of yearly water consumption
- **Pm** (\$ / year) yearly cooling system related maintenance cost
- **Pu** (\$ / year) cost differences coming from the effect of cooling systems on equivalent unavailability
- **A** (1 / year) annuity rate, function of plant economic lifetime and interest rate of the currency

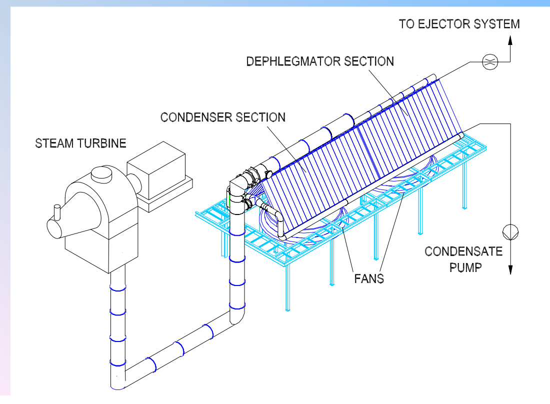
3. Economics of HELLER System Serving an 800 MW_e Coal Fired Supercritical Cycle

3.1 The investigated cooling system variants

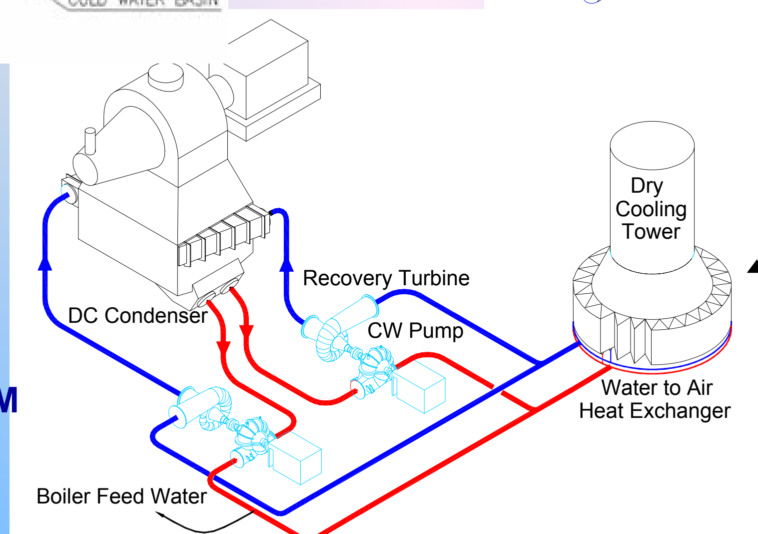
EVAPORATIVE SYSTEM

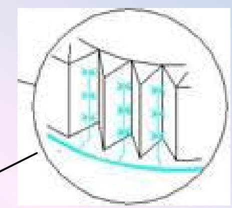


DIRECT ACC



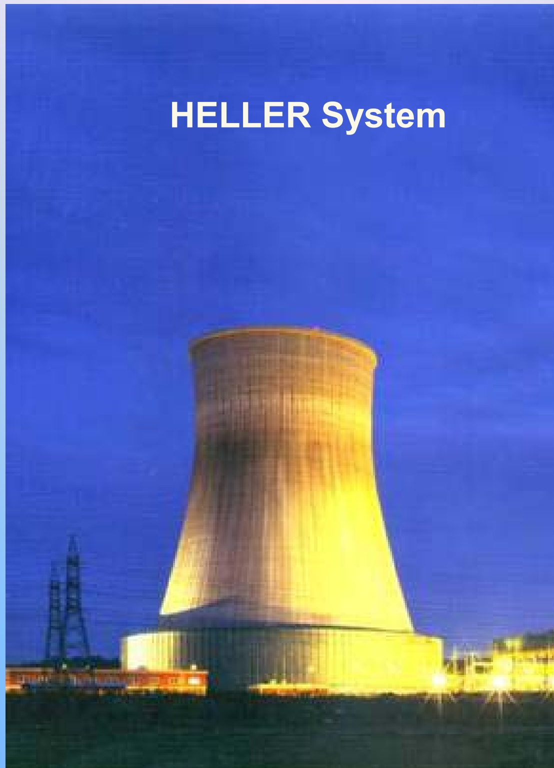
HELLER SYSTEM

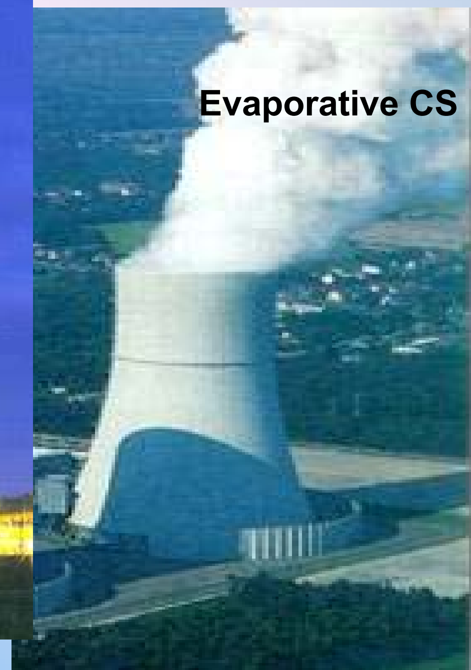




Supplementary Spraying

3.1 The investigated cooling system variants – cont.





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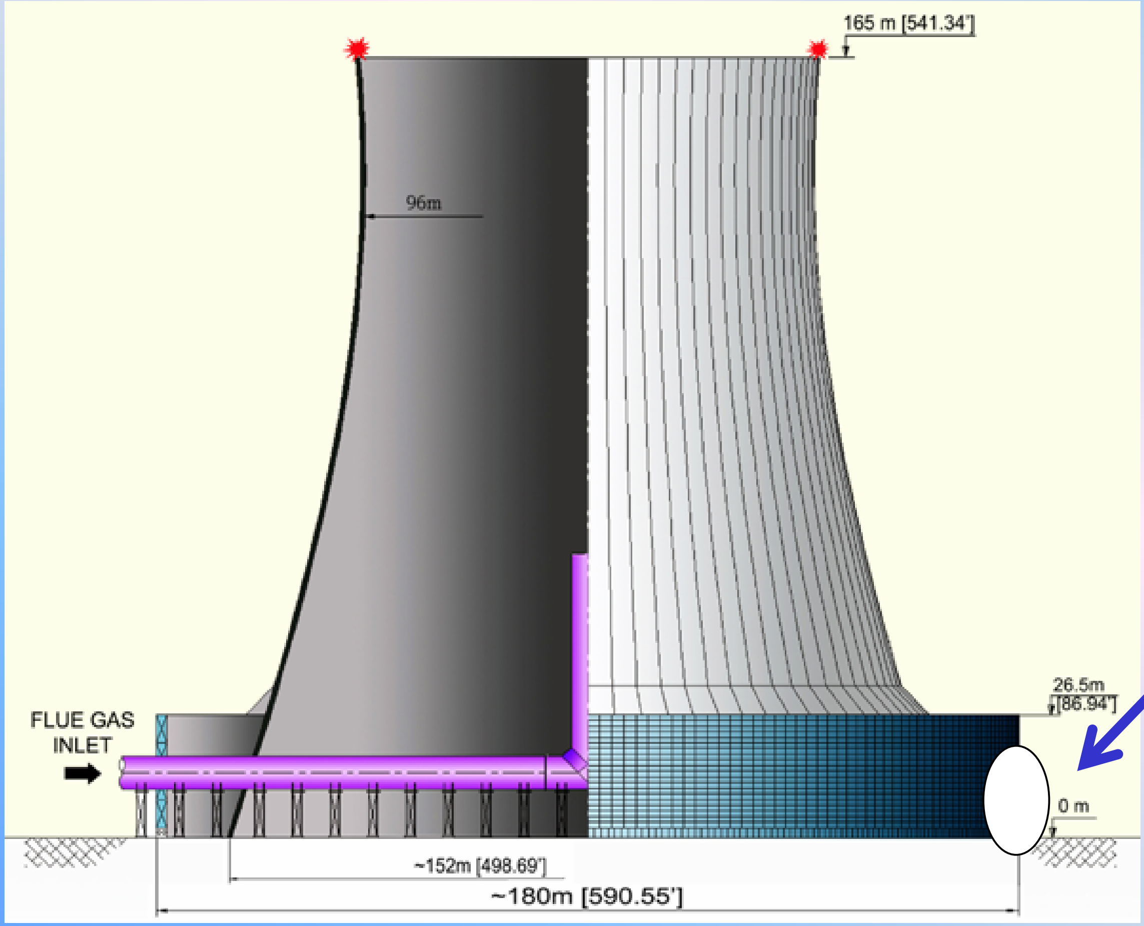
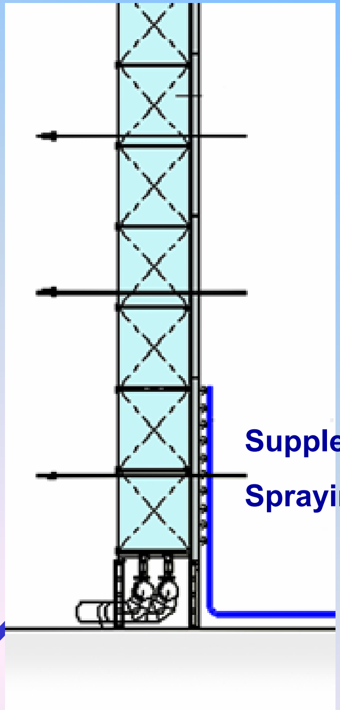
3.1 The investigated cooling system variants – cont.

HELLER: Indirect Dry Cooling Heller System with Natural Draft and DC Jet Condenser & optional Supplementary Water Spraying to enhance summertime capability; flue gases to be exhausted through the tower





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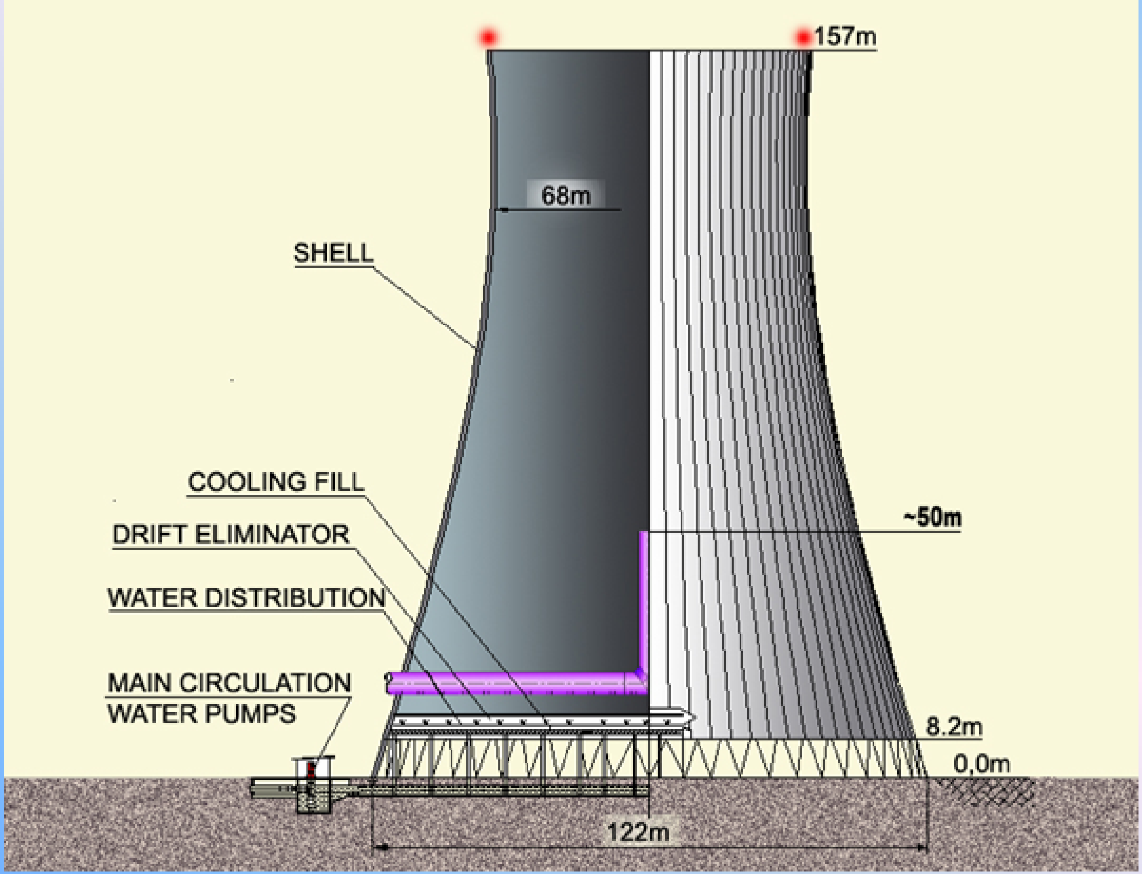
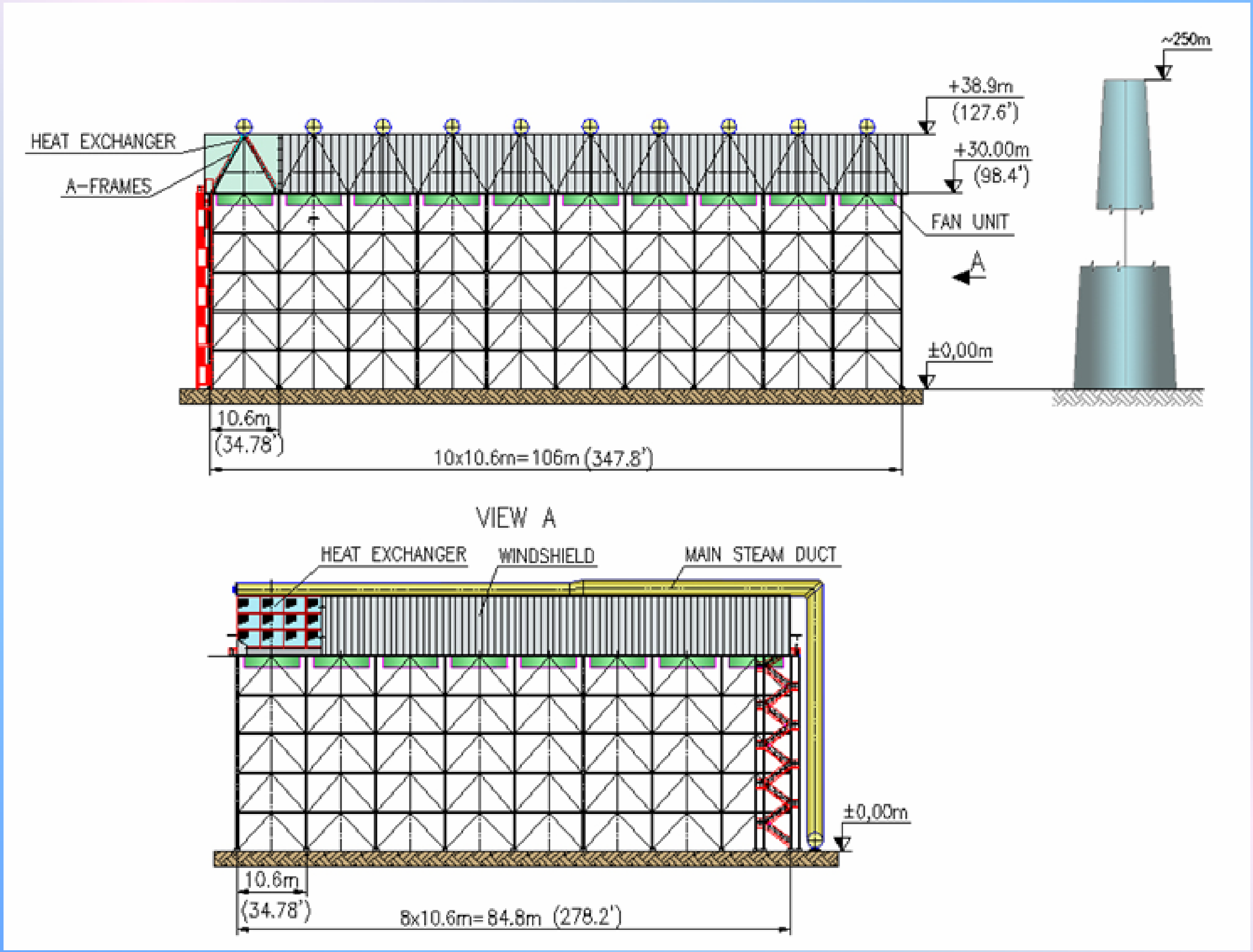
3.1 The investigated cooling system variants – cont.

Evaporative: **Natural Draft Evaporative Cooling System with Surface Condenser; flue gases to be exhausted through the tower**



3.1 The investigated cooling system variants – cont.

Direct ACC: **Mechanical Draft Direct Dry Cooling System; flue gases to be exhausted through a separate chimney of 250 m**



3.2 Assumed conditions and main starting data for the evaluation

✓ Site conditions

Site Conditions	HELLER	EVAPORATIVE	DIRECT ACC	REMARKS
Ambient Temperature Range	-16,6°F - +100,4°F			see also duration curve in [6]
Design Point Ambient Temperature (dry bulb)	54,0 °F			
Design Point Relative Humidity	30%			
Site Elevation	5100 feet			Note the high elevation!

3.2 Assumed conditions and main starting data for the evaluation – cont.

✓ Main design point data of the power cycle

Power Cycle Thermal Data (per unit)	HELLER	EVAPORATIVE	DIRECT ACC	REMARKS
Gross Turbine Output at Design Point (MWe)	**775.54**	**786.25**	**775.54**	
Gross Turbine Output at Design Point reduced by the auxiliary power except that of the cooling system (MWe)	**745,54**	**756,25**	**745,54**	**The assumed aux. power (excl. that of cooling system): 30 MWe is deducted from the gross output** **see assumed turbine characteristic curves in [6]**
Heat to be Dissipated at Design point (MMBtu/h)	**3 124**	**3 088**	**3 124**	
Design Point Turbine Back-pressure (inHgA)	**2,37**	**1,32**	**2,37**	
Cooling System Auxiliary Power at Design point (MWe)	**5,46**	**6,60**	**8,07**	**see in [6]**
Net Turbine Output at Design Point (MWe)	**740,08**	**749,65**	**737,47**	**Cooling system auxiliary power + other 30 MWe are deducted**
Overall ITD at design point (°F)	**52,9 °F**	**Not applicable**	**52,9 °F**	**saturated steam temperature at turbine exhaust minus ambient air temperature**

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3.2 Assumed conditions and main starting data for the evaluation – cont.

✓ **Assumed conditions for the economic evaluation**

Data for Economic Evaluation	HELLER	EVAPORATIVE	DIRECT ACC	REMARKS
Plant Economic Life-span	25 years			See sensitivity charts in Sec.3.4 showing the effects of variation in the assumed economic parameters
USD Interest Rate	3,0%			
Annuity Rate	0,0574 p.a			
Load Factor	85%			
Electricity Selling Price	3,5 cent / kWh			
Specific Water Cost	50 cent / m3	35 cent / m3	-	

Only in case of VAR 4 when supplementary spraying is applied above 77°F dry bulb temp.

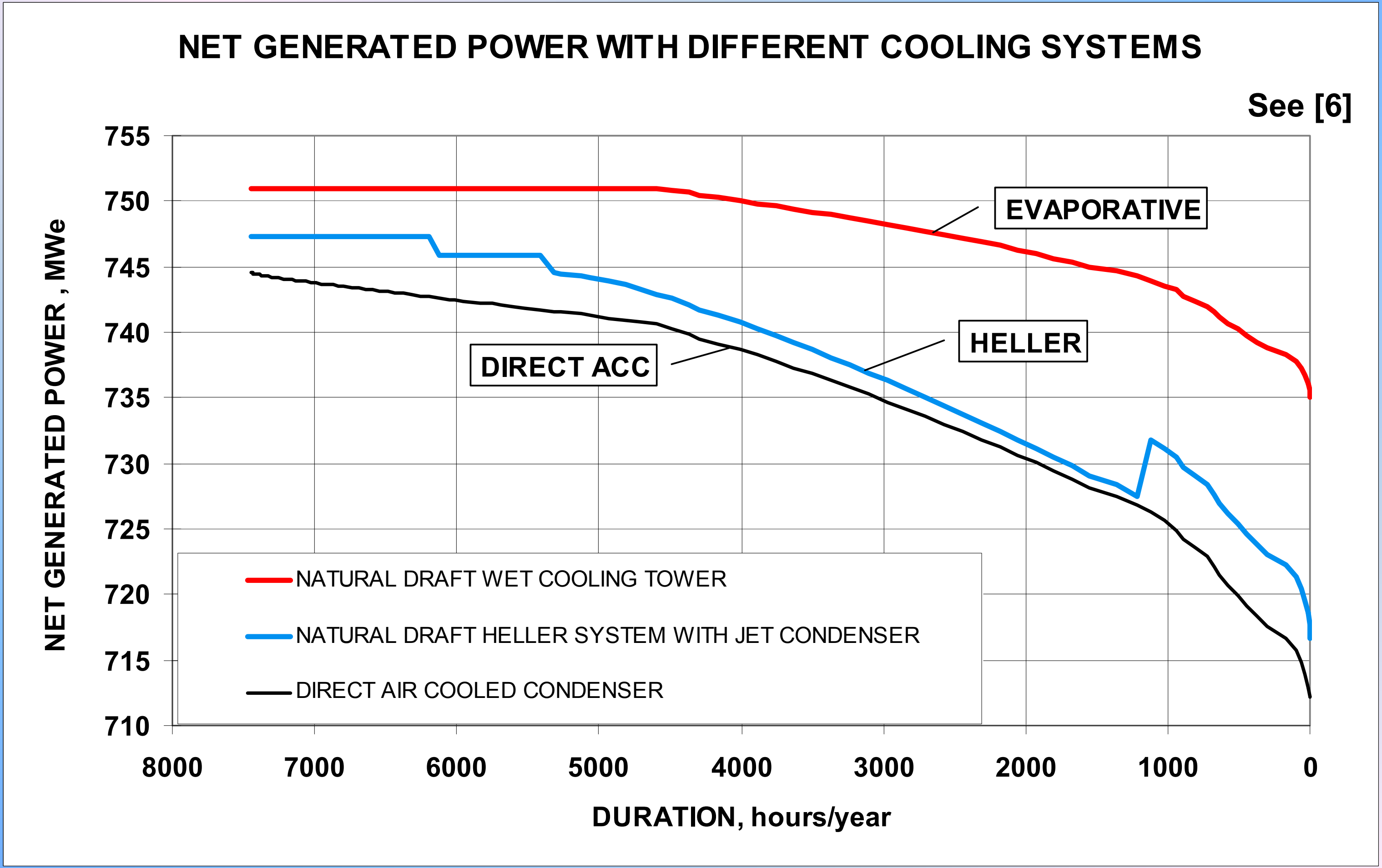
3.3 Main cost items and results of the investigation

✓ Results of thermal calculation

Result of Thermal Calculation (per unit)	HELLER VAR4	EVAPORATIVE	DIRECT ACC	REMARKS
Electricity Generation (GWh / year)	5.534,6	5.617,4	5.522,4	- see power duration curves in [6] - also basis for calc. equ. unavailability cost diff.
Cooling System Auxiliary Power Consumption (GWh / year)	36,24	49,14	52,90	- see power duration curves in [6]
Net Electricity (GWh / year)	5.498,4	5.568,2	5.469,5	- see power duration curves in p.15
Average net output (MWe)	738,53	747,92	734,66	
Water consumption at design point (gpm)	0	5.676	0	
Yearly water consumption (acre ft / year)	295,5 *	7.569	0	* In case of Var 4. - when spraying option is applied above 77°F dry bulb temp.

3.3 Main cost items and results of the investigation – cont.

✓ **Results of thermal calculation – cont.**



3.3 Main cost items and results of the investigation – cont.

✓ Investment Costs – Item 1.

Investment Costs million $ (2004 price level)	HELLER VAR 4.	EVAPORATIVE	DIRECT ACC	Remarks
COOLING SYSTEM COMPLETE	**54.29**	**38.33**	**51.20**	
A. Credit for substituting chimney with stack-in-tower	-2	-2	-	
B. Credit for eliminating FGD recuperator	-2.5	-2.5	-	
C. Extra cost for tower surface painting	-	+2.4	-	
TOTAL COOLING SYSTEM RELATED INVESTMENT COSTS for comparable scopes 10^6 $ per unit	**49.79**	**36.23**	**51.2**	

- The above specified investment costs do not include that of the cooling water make-up supply system for the Evaporative CS or that of the spraying water supply for those variants of HELLER System where the supplementary spraying option is used. These investment costs are included in the specific price of make-up water (35 cent / m^3 for Evaporative CS and 50 cent /m^3 for HELLER System spraying water).
- However, when the maintenance costs are assessed, the maintenance of the water supply system shall also be taken into account.

3.3 Main cost items and results of the investigation – cont.

✓ Costs or gains coming from differences in electricity production – Item 2.

- The electricity generation and cooling system auxiliary power consumption values and the net electricity production are given in page 14 (see table) and page 15 (see chart).
- Considering the net electricity produced by the unit equipped with HELLER System as base value, the differences in electricity production are multiplied by the assumed specific electricity selling price of 3.5 cent/kWh, to determine the costs or gains.

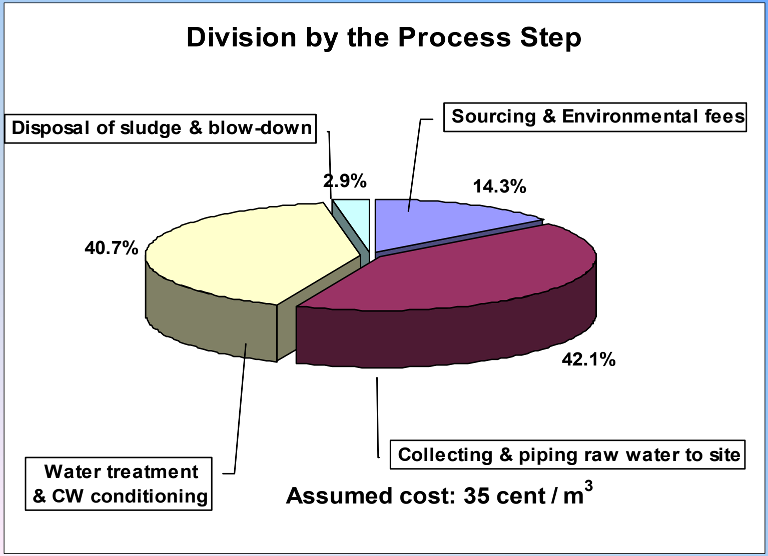
Results of Economic Evaluation		**HELLER VAR 4.**	**EVAPORATIVE**	**DIRECT ACC**
Cost of Difference in Net Electricity Production	Yearly 10^6 \$/year	BASE	-2.45 (gain)	1.01 (cost)
	Present Value 10^6 \$	BASE	-42.62 (gain)	17.62 (cost)

- Sensitivity charts show the effect of changing electricity selling price (see Sec. 3.4).

3.3 Main cost items and results of the investigation – cont.

✓ Cost of water consumption – Item 3.

- Cost of make-up water supply for the Evaporative CS shall cover all process steps including: Sourcing & Environmental Fees, Collecting & Piping Raw Water to Site, Water Treatment and CW Conditioning, Disposal of Sludge & Blow-Down. In the investigated case, where the distance of site from water source is about 25 miles, the assumed specific water cost is 35 cent/m³. The required investment cost is about $ 14 million.



- For the supplementary spraying of HELLER System at VAR 4. a significantly lower quantity but better quality make-up water is needed. Its estimated specific cost is 50 cent/m³. The required investment cost is about $ 2.5 million.

- Evaluating the yearly water consumption values with the specific costs:

Results of Economic Evaluation		HELLER VAR 4.	EVAPORATIVE	DIRECT ACC
Cost of make-up water	Yearly 10^6 \$/year	0.18	3.27	0
	Present Value 10^6 \$	3.18	56.92	0

3.3 Main cost items and results of the investigation – cont.

✓ Maintenance cost – Item 4.

Results of Economic Evaluation		HELLER VAR 4.	EVAPORATIVE	DIRECT ACC
Maintenance Costs	Yearly 10^6 \$/year	0.5	0.91	1.23
	Present Value 10^6 \$	8.67	15.77	21.4

- See considerations about maintenance cost of HELLER System in [6]. The assumed maintenance cost is about 0.96% referred to the investment costs of the „comparable scope" of HELLER System plus that of the water supply for supplementary spraying. (This assumed maintenance cost is higher than the recorded figures in reference plants.)
- The assumed maintenance costs of Evaporative CS is about 1.8% of the investment costs of the cooling system plus that of the make-up water supply system. The main cost items are coming from repairing the surface condenser and its continuous on-line cleaning plus the periodical renewal of tower surface protective painting. Further costs occur at the extensive water supply system and at the power cycle (related to CPP ion exchanger resin and to boiler cleaning).
- The major maintenance cost item at the direct ACC is related to the extensive number of large diameter fans, gearboxes and their driving motors. Maintenance cost referred to the CS investment cost is 2.4% in line with suggestions in [2]. However, at a supercritical coal fired unit several important surplus cost items may occur at the power plant because the effect of cooling system (such as need for more frequent regeneration of CPP and change of resin, and also boiler cleaning due to the AVT water chemistry). Also, maintenance of additional equipment like flue gas recuperator and the separate chimney should have been debited against the cooling system in a comparative evaluation.

3.3 Main cost items and results of the investigation – cont.

✓ Cost of differences in equivalent unavailability – Item 5.

Results of Economic Evaluation		HELLER VAR 4.	EVAPORATIVE	DIRECT ACC
Cost of diff. in equivalent unavailability	Yearly 10^6 \$/year	BASE	1.38	0.77
	Present Value 10^6 \$	BASE	23.96	13.46

- Effects reducing efficiency and performance or causing forced outages and extended maintenance periods are the main sources of unavailability. The percentage equivalent unavailability difference can be regarded as proportional reduction in electricity generation.
- It is not only the unavailability of a cooling system itself shall be taken into account but also its impact on the unavailability of the power cycle.
- Considerations are given about HELLER System unavailability in [6].
- Main source of Evaporative CS unavailability is the reduced capability of surface condenser due to depositions in tubing and reduced power during on-line repairing or possibility of forced outages. [1] Further reductions may come from negative effect on boiler deposition / cleaning due to water chemistry problems. The surplus equivalent unavailability compared to HELLER System is estimated 0.4-1%. Here 0.7% was considered.
- For the present calculations 0.4% is used as the surplus unavailability of Direct ACC. Its major source is related to the performance losses due to the occasional trips of fans and effect of warm air recirculation under certain circumstances. In lack of sufficient data for such indirect effects as those arising from the AVT water chemistry and reduced efficiency of CPP are not considered here.

3.3 Main cost items and results of the investigation – cont.

✓ **Summary of the present value based cost differences**

Results of Economic Evaluation	**HELLER** VAR 4.	**EVAPORATIVE**	**DIRECT ACC**
Sum of present value cost items 1-5. (Million $)	61.64	90.26	103.68
Total present value based cost differences referred to HELLER (Million $)	**BASE**	**28.62**	**42.04**

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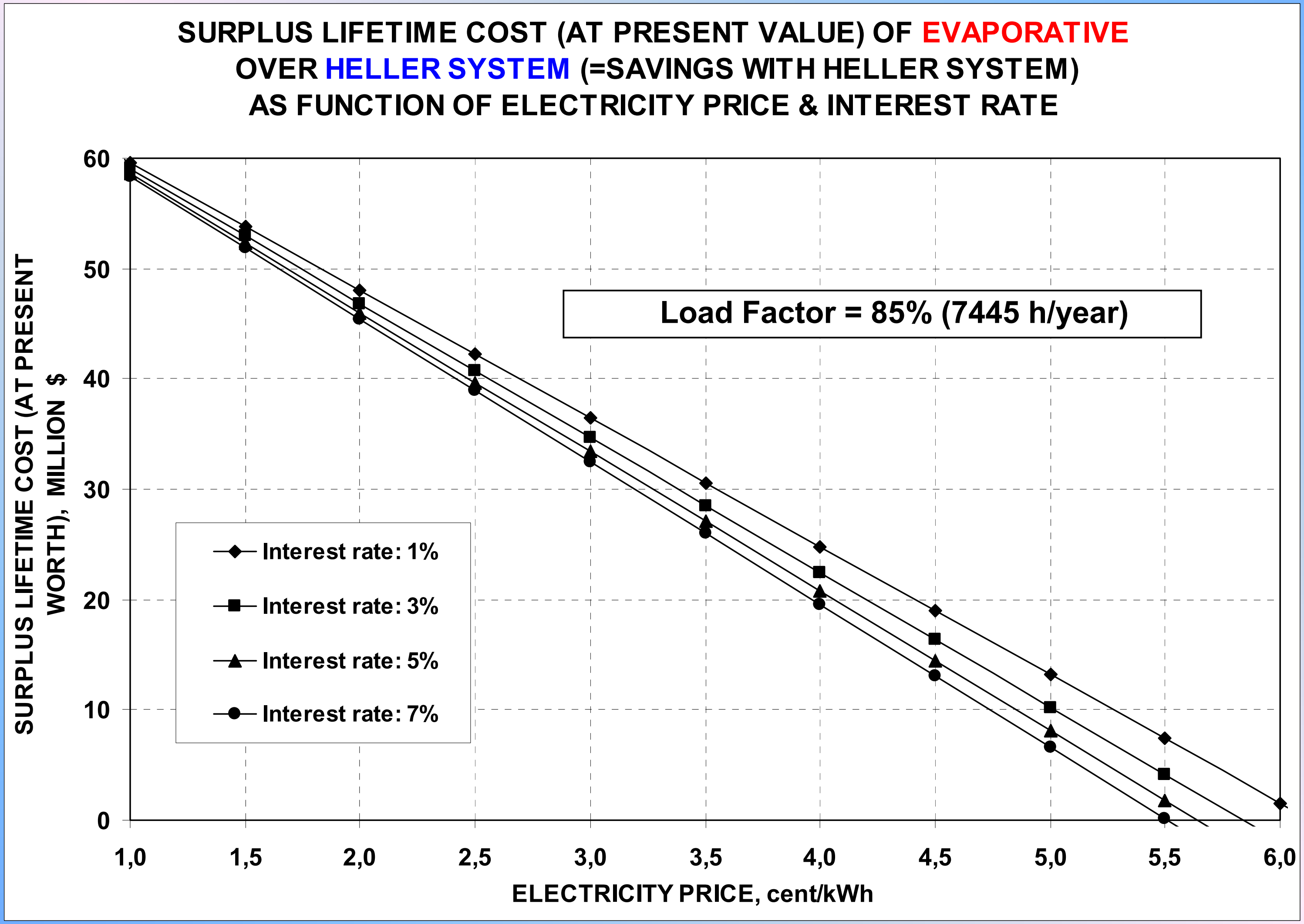
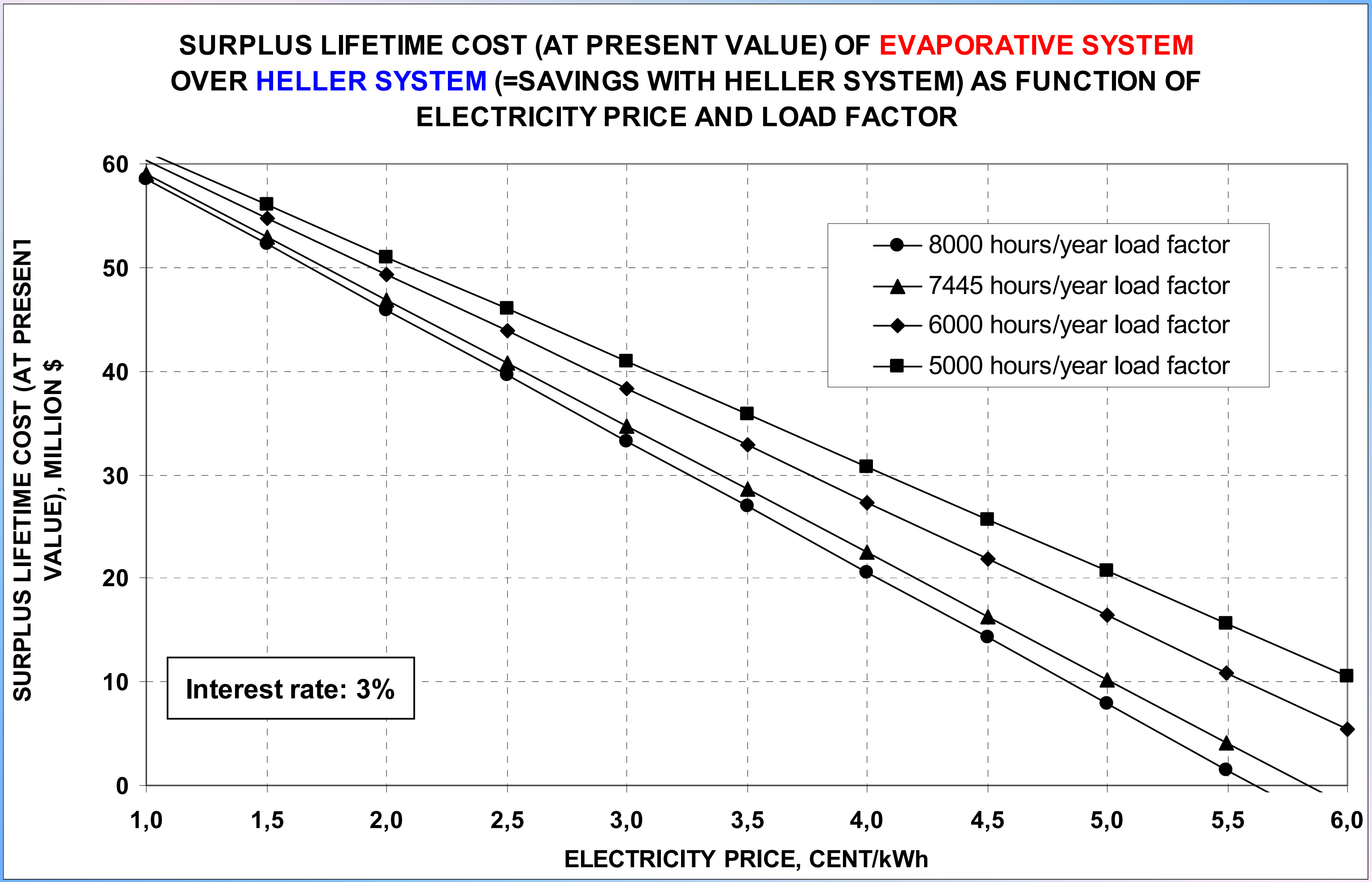
3.4 Sensitivity analysis



3.4 Sensitivity analysis – cont.



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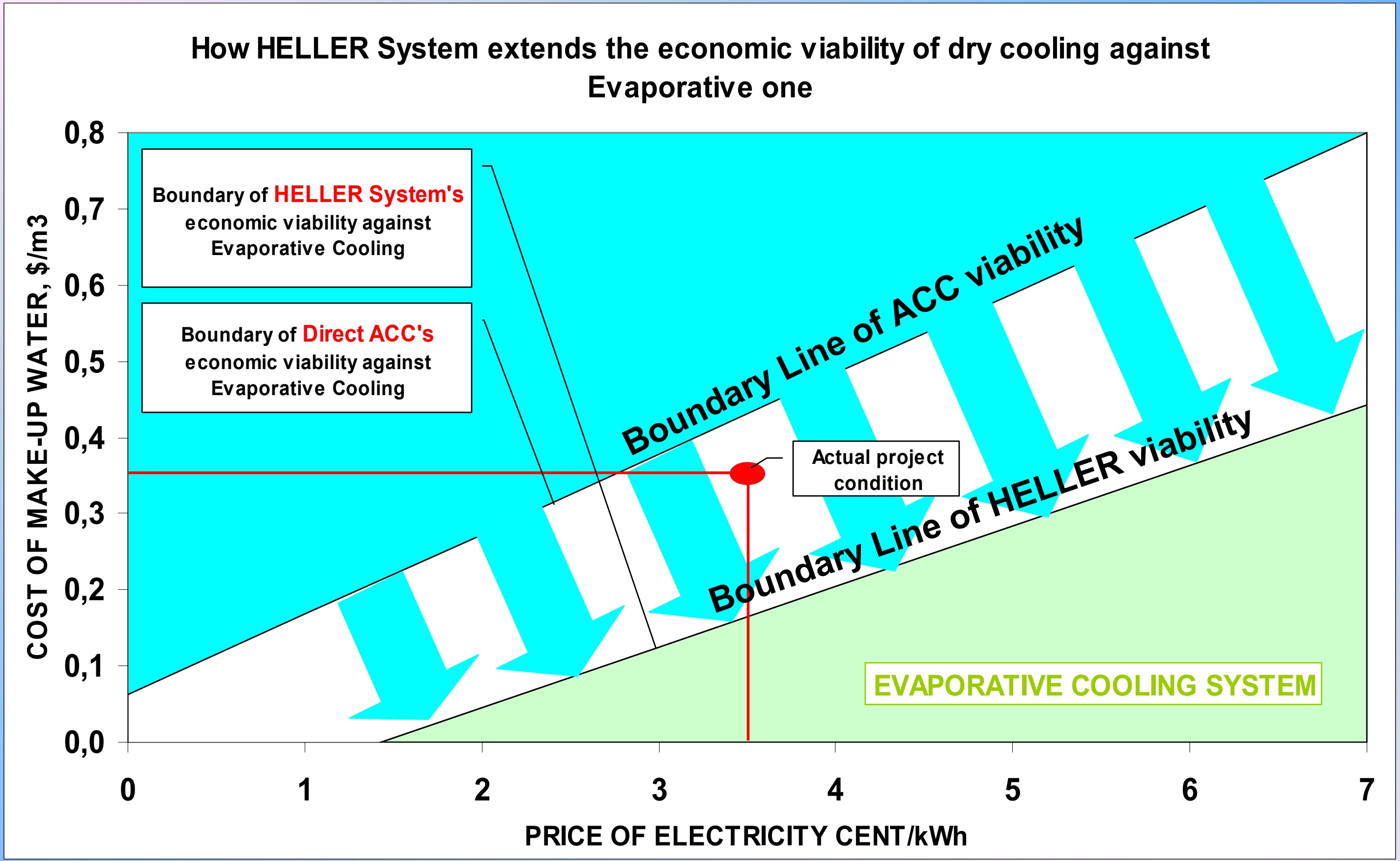
3.4 Sensitivity analysis – cont.



- The above chart shows in a coordinate of specific electricity price and make-up water cost the economic viability of the dry cooled systems against the evaporative cooling. It is clearly visible how natural draft HELLER System extends the economic feasibility of dry cooling solutions.

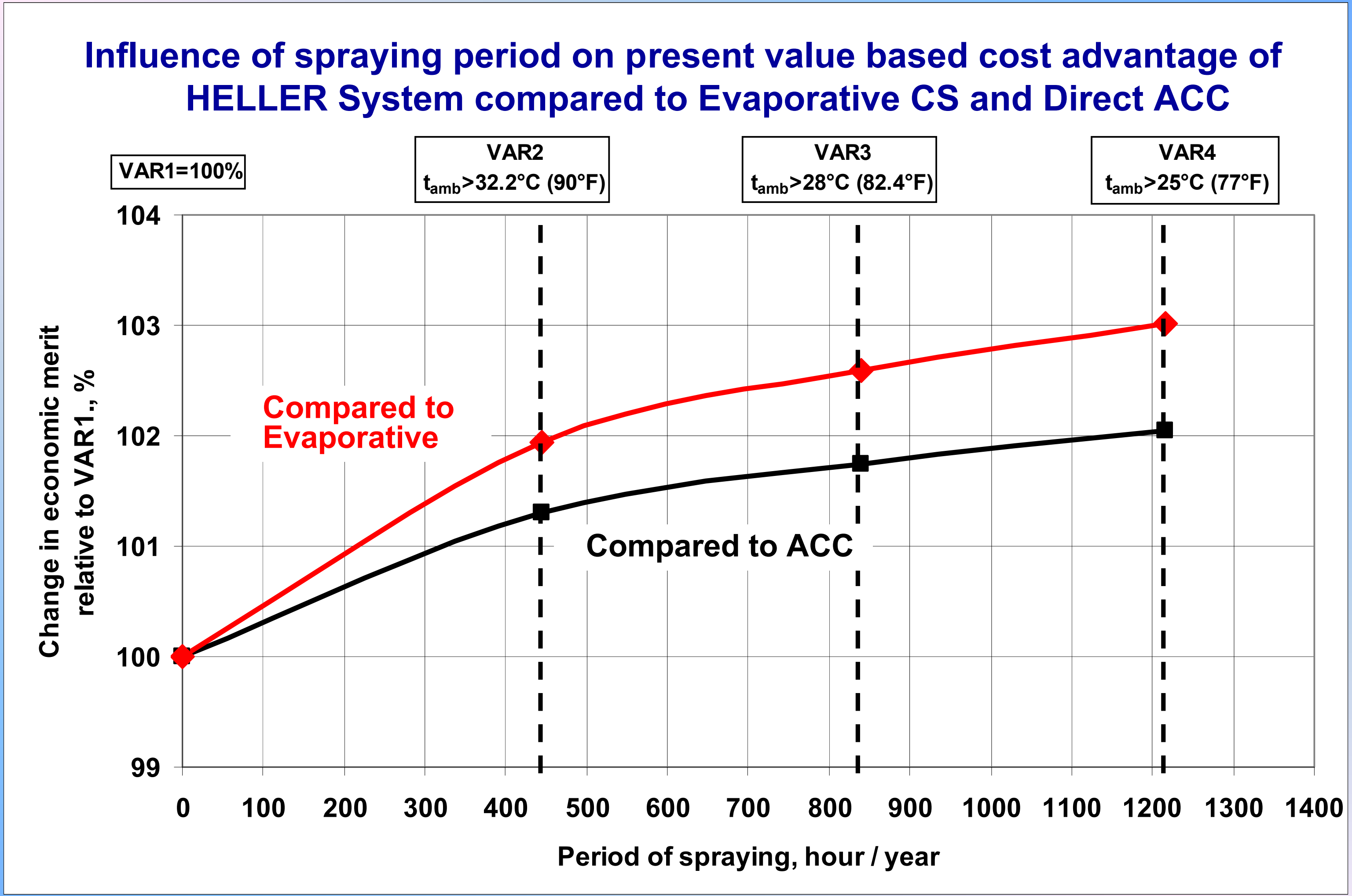
3.5 Economic assessment of supplementary spraying for summer-time performance enhancement of HELLER System

- Four variants were investigated differing in the period of supplementary spraying and thus the ambient temperature above which the spraying is applied. The base variant (VAR 1) is the all-dry HELLER System, i.e. no spraying at all. However, the variant introduced in details is VAR 4, when spraying is started at 25°C (77°F), resulting in 1215 hours/year operation time, the longest period of spraying among the investigated variants.
- The effect of varying periods of supplementary spraying has been investigated as follows:

Amb. temp. above which spraying starts:	**VAR 1. No spraying = All-dry**	**VAR 2. Spraying > 32.2°C (90 °F)**	**VAR 3. Spraying > 28°C (82.4°F)**	**VAR. 4. Spraying > 25°C (77°F)**
Period of spraying	0	444 h/year	840 h/year	1215 h/year
Annual spraying water consumption	0	133 200 m^3/year	252 000 m^3/year	364 500 m^3/year
Economic merit relative to Direct ACC (i.e. improvement in present value)	41.2 million $ 100%	41.74 million $ 101.31%	41.92 million $ 101.75%	42.04 million $ 102.04%
Economic merit relative to Evaporative CS (i.e. improvement in present value)	27.78 million $ 100%	28.32 million $ 101.94%	28.50 million $ 102.59%	28.62 million $ 103.02%

- Independently from the periods of spraying enhancement, the specific spraying water cost (50 c/m^3), the electricity selling price (3.5 c/kWh) and the maintenance costs are assumed remaining constant.

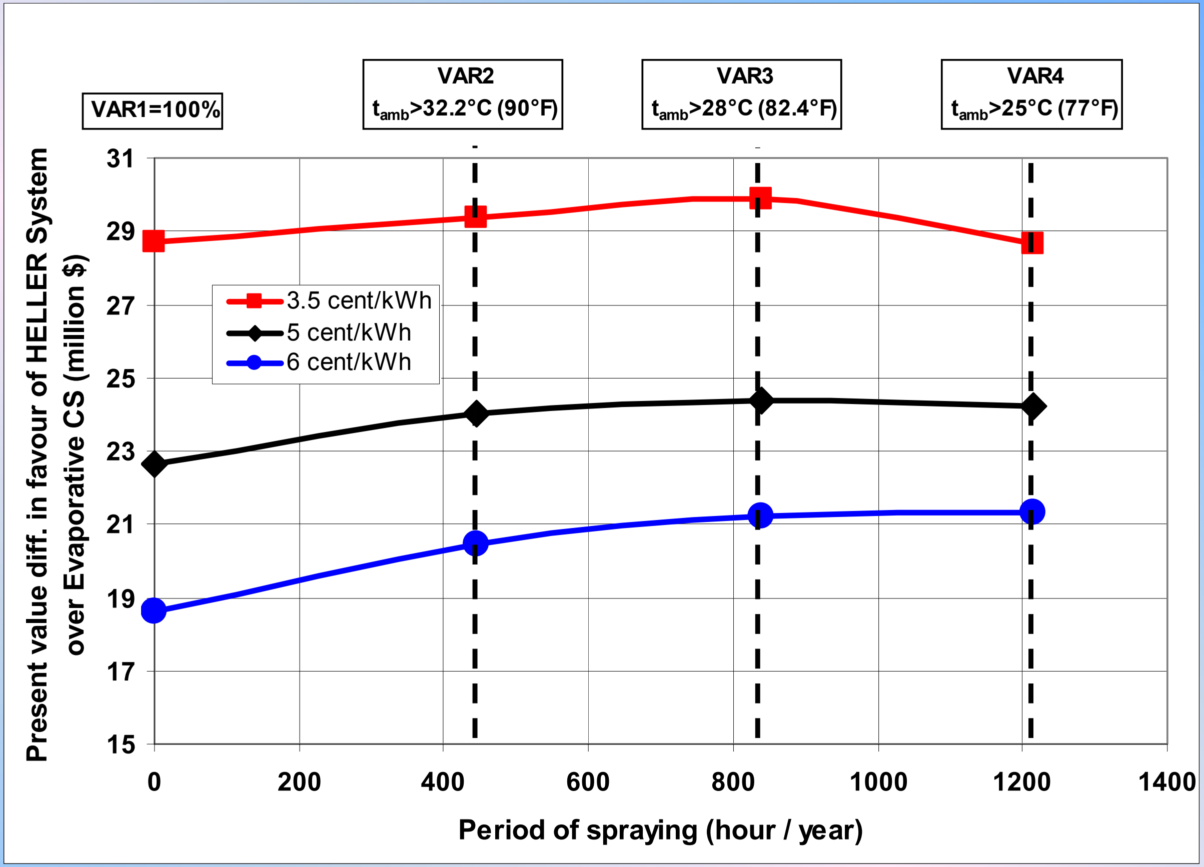
3.5 Economic assessment of supplementary spraying… - cont.



Constant specific spraying water cost and electricity price and unchanged maintenance cost assumed

3.5 Economic assessment of supplementary spraying… - cont.

Variation of present value differences in favor of HELLER System over Evaporative CS at varying specific peak time electricity price, spraying water cost and changing maintenance cost



- Assumed spraying water cost: 35 c/m³ at VAR 2; 42 c/m³ at VAR 3; 50 c/m³ at VAR 4
- Reduction in yearly maintenance cost, compared to that of VAR 4: - 20 th $ at VAR 3; - 40 th $ at VAR 2; -50 th $ at VAR 1

3.6 Evaluation of results of HELLER System serving an 800 MW_e Supercritical Cycle

1) As the summary of the present value based cost differences (see Sec. 3.3, p.21) show, the HELLER System has a distinctive economic advantage at the actual conditions of the investigated project case - to reach equivalence with it, the investment cost of the Evaporative CS should be reduced to 21% and that of the Direct ACC to 18% of their original value.
2) The economic advantage of HELLER System is maintained in a practical and wide range of conditions. Based on sensitivity charts and the economic viability envelope (see Sec. 3.4), the break-even water costs and break-even electricity prices are summarized herein showing how much the HELLER System can extend the economic viability of dry cooling against wet cooling.

Economic viability of dry cooling	**Break-even water costs in cent / m^3** (at 3.5 cent/kWh)	**Break-even electricity price cent/kWh** at water costs: 35 cent/m^3	40 cent/m^3
HELLER vs. EVAPORATIVE	**16.37**	**5.84**	**6.47**
Direct ACC vs. EVAPORATIVE	**43.19**	**2.72**	**3.19**

3.6 Evaluation of results of HELLER System serving an 800 MW_e Supercritical Cycle – cont.

3) The investment costs of the natural draft HELLER System is in the same range as that of the direct ACC (the former is higher by 6%), however if credited with the cost savings of avoiding the use of a high chimney and a flue gas recuperator (due to exhausting flue gases via the tower), the investment cost of the HELLER System is even a bit lower. The investment costs of the evaporative cooling system is lower by 28 % than that of the HELLER System, however if the investments for providing the required capacity of cooling water make-up is also considered, this difference is nearly diminished.

4) The unit equipped with Evaporative Cooling System generates the most electricity, however only by 1.3% more than the unit with HELLER System.

5) The natural draft HELLER System represents an outstanding availability with minimum maintenance due to its system and equipment features such as static air moving equipment, sectionalized air coolers, a CW circuit integrated with the feed water cycle and application of DC jet condenser. In certain aspects, the HELLER System complements the supercritical power cycle and supports it in exploiting its full potentials – resulting in an improved availability and maintenance of the complete power unit.

3.6 Evaluation of results of HELLER System serving an 800 MW_e Supercritical Cycle – cont.

6) The power unit equipped with the HELLER System has smaller environmental impact (ground level concentration of pollutants, noise emission, plume, water consumption and blow-down) than the Evaporative CS.

7) As explained in Sec. 3.5, besides the all-dry HELLER System (VAR 1), other variants were investigated for applying „supplementary spraying" throughout different periods. Such spraying serves both, optimal matching of the „cold end" (LP turbine and cooling system) and increasing the generated electricity in summer peak periods. In the economic evaluation VAR 4 is presented in details where the spraying starts above 25°C (77°F) corresponding to 1215 h/year operation. Further reduced periods of spraying were considered, when importance of the surplus electricity generation is smaller and the main reason of spraying is the optimal matching of the „cold end" and avoiding derating. Evaluating the economic effect of these variants with unchanged conditions (specific electricity price, spraying water cost and maintenance cost) the economic result remains within 3% compared to the Evaporative CS (see chart in Sec. 3.5, p. 26). Whereas considering varying values for the above cost items the relative effect will be larger (see chart in Sec. 3.5, p. 27).

3.6 Evaluation of results of HELLER System serving an 800 MW_e Supercritical Cycle – cont.

- EGI thinks, on technical and economic reasons, supplementary spraying should not be used over a period of about 1500 h/year. Depending on the actual project circumstances and opportunities probably the most advisable period is around 800 h/year. From technical aspects (to avoid unwanted deposition on air coolers and surplus maintenance costs) when determining the period of spraying, it is important to properly evaluate the quality of water to be used as well as the ambient air quality.

- Exhausting flue gases via the cooling tower (stack-in-tower) may improve significantly the economics of coal fired power plants [5], [6]. This method is applicable for both natural draft solutions (HELLER and Evaporative). However, in case of the HELLER System it results in higher economical gain and a significantly lower ground level pollutant concentration (SO_2, NO_X) - e.g. the yearly average value is nearly halved if compared to the Evaporative CS option and less than half of the value when applying mechanical draft direct ACC and a separate chimney of 250 m high. It shall be mentioned that imission values remain well within the limits specified by the relevant standards in all three cases. However, considering the possible existing „back-ground" pollution and the future development potential of the area, to keep imission as low as possible represents a high value.

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4. Economic Assessments of HELLER Systems Serving CCPP

GEA - EGI has designed / supplied / constructed cooling systems for more than 10,000 MW_e Combined Cycle Power Plant (CCPP) capacity – including the largest dry cooled CCPP in the world (see in [6]). In several cases on the request of the end-users, EGI has made contributions to present value based economic life-cycle investigations. Herein only the summary of results of two case studies (evaluating dry cooling alternatives for CCPP) are introduced.

3 x 777 MW_e Gebze & Adapazari
Intergen, Enka, Bechtel

1400 MW_e Bursa
EÜAS, MHI

4.1 Results of an investigation for an 800 MW_e Combined Cycle Power Plant

- Another paper by EGI submitted for this EPRI conference [6] – introducing the technical aspects of HELLER System – gives a comparison of effects by dry cooling systems (a natural draft HELLER System and a mechanical draft Direct ACC) on the environmental impacts of an 800 MW_e CCPP (see Sec. 5.1 in [6]). The comparison shows that in terms of noise emission, CO_2 emission, opportunity to reduce ground level concentration of pollutants, the HELLER System is superior to the ACC. However, the visual impact of the natural draft HELLER System is greater.
- Herein only the results of the economic evaluation are shown:

Summary Table	HELLER System natural draft	Direct ACC mechanical draft
Total cooling system related investment costs (auxiliary cooling excluded)	29.3 million US$	30.2 million US$
Surplus total life cycle cost(incl. investment) in present value	**base**	**+ 16 million US$**

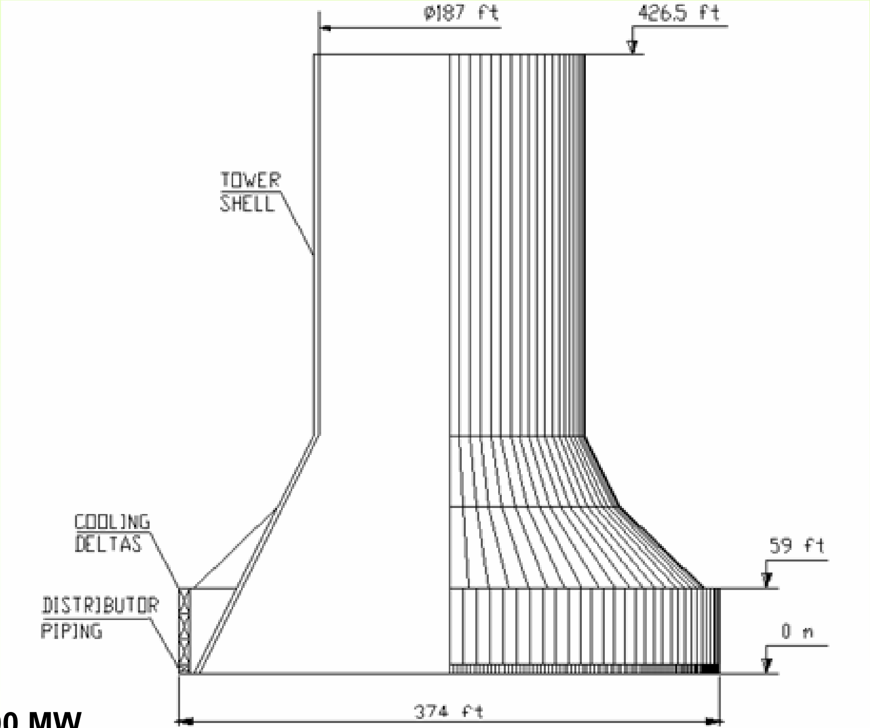
- It is remarkable that for the specific application, the investment cost of the natural draft HELLER System is practically the same as that of the mechanical draft direct ACC, whereas its present value based total life-cycle cost is significantly lower. The difference in favor of the HELLER System is about 50% of the investment cost.

4.2 Results of an investigation for a 500 MW$_e$ Combined Cycle Power Plant

- Similarly to the evaluation method presented in Sec. 3, a present value based economic assessment has been prepared comparing a natural draft dry cooling HELLER System and a mechanical draft Direct ACC serving a 500 MW$_e$ combined cycle power plant.
- Some of the starting data were taken from a PIER/EPRI Technical Report [4].

✓ ***The investigated variants***

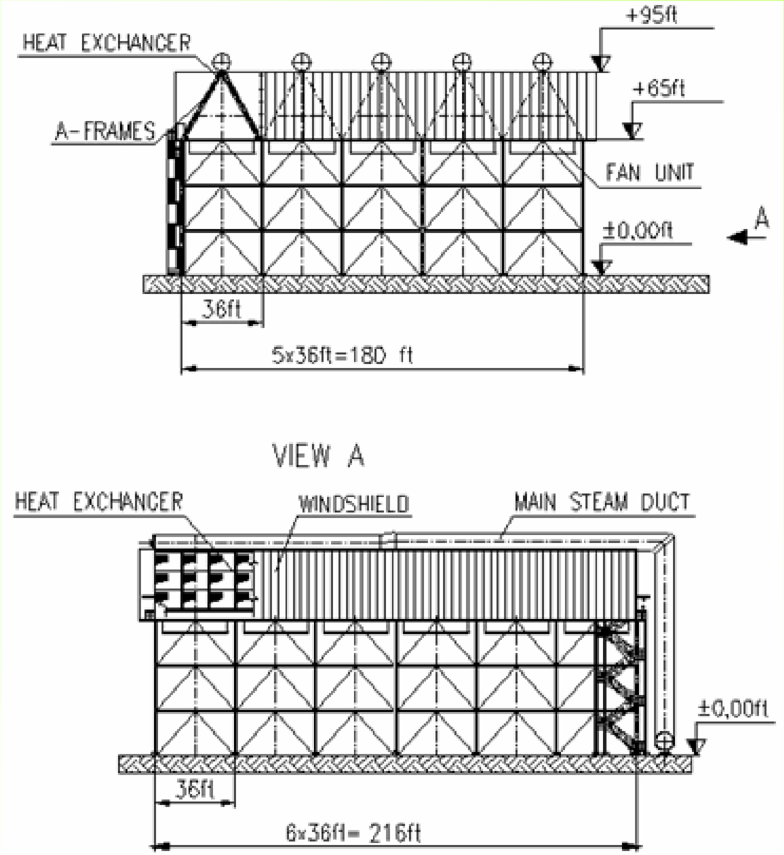
HELLER System: Indirect Dry Cooling HELLER System with DC Jet Condenser and Natural Draft (Structural Steel Aluminum Clad) Tower



The dimensions of the tower considered for the 500 MW$_e$ CCPP are similar to one tower of the Al Zara Power Plant

✓ *The investigated variants – cont.*

Direct ACC: Mechanical Draft Direct Dry Cooling System



✓ *Main starting data*

MAIN STARTING DATA	HELLER	DIRECT ACC	REMARKS
Ambient Temperature Range	+45.1°F - +106°F		See also duration curve [6]
Design Point Ambient Temperature (dry bulb)	65.0°F		
Design Point Relative Humidity	50%		
Site Elevation	320 feet		
Plant Economic Life-span	25 years		See sensitivity charts showing the effects of variation in the assumed economic parameters in page 38
USD Interest Rate	4.0%		
Annuity Rate	0.064 p.a		
Load Factor	75%		
Electricity Selling Price	3.5 cent / kWh		
Gross Turbine Output at Design Point (MWe)	170	170	See assumed turbine characteristic curves in [6]
Heat to be Dissipated at Design Point (MMBtu/h)	979.87	979.87	
Design Point Turbine Back-pressure (inHgA)	2.5	2.5	
Cooling System Auxiliary Power at Design Point (MWe)	1.68	3.17	
Net Turbine Output at Design Point (MWe)	168.3	166.8	Only cooling system auxiliary power is deducted
Overall ITD at Design Point (°F)	44.0	44.0	Saturated steam temperature at turbine exhaust minus ambient air temperature

✓ ***Results of the investigation***

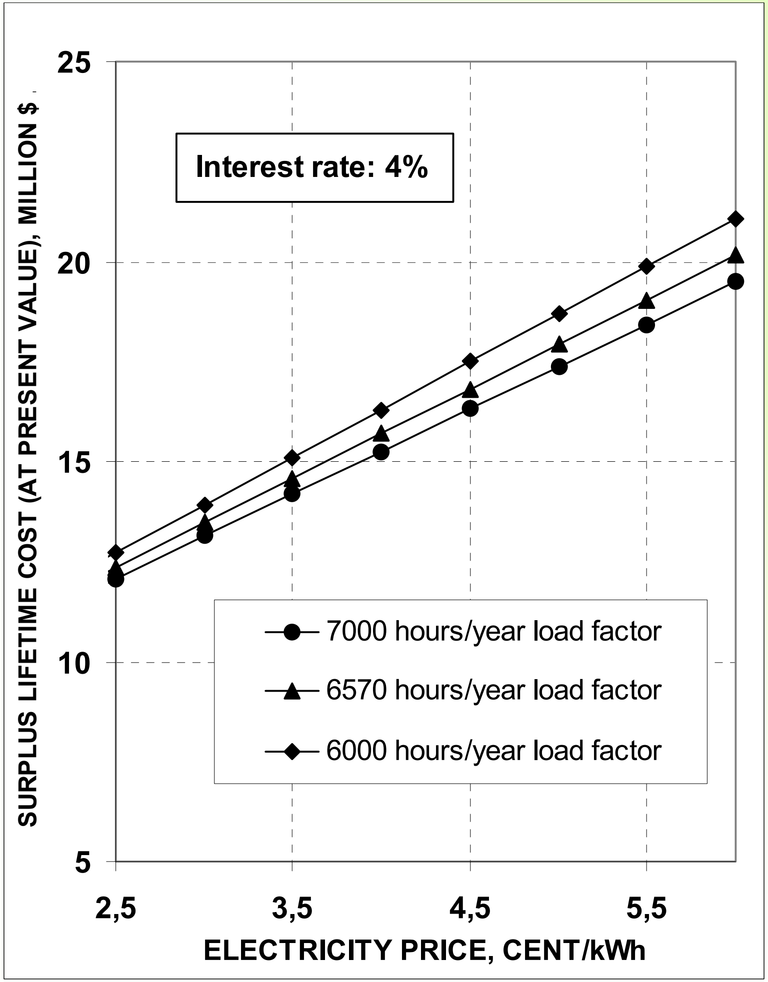
- The results of the thermal calculation such as yearly electricity generation, cooling system auxiliary power consumption, net electricity and average net output are reflected by the power duration curves given in [6].
- The main results of the economic evaluation:

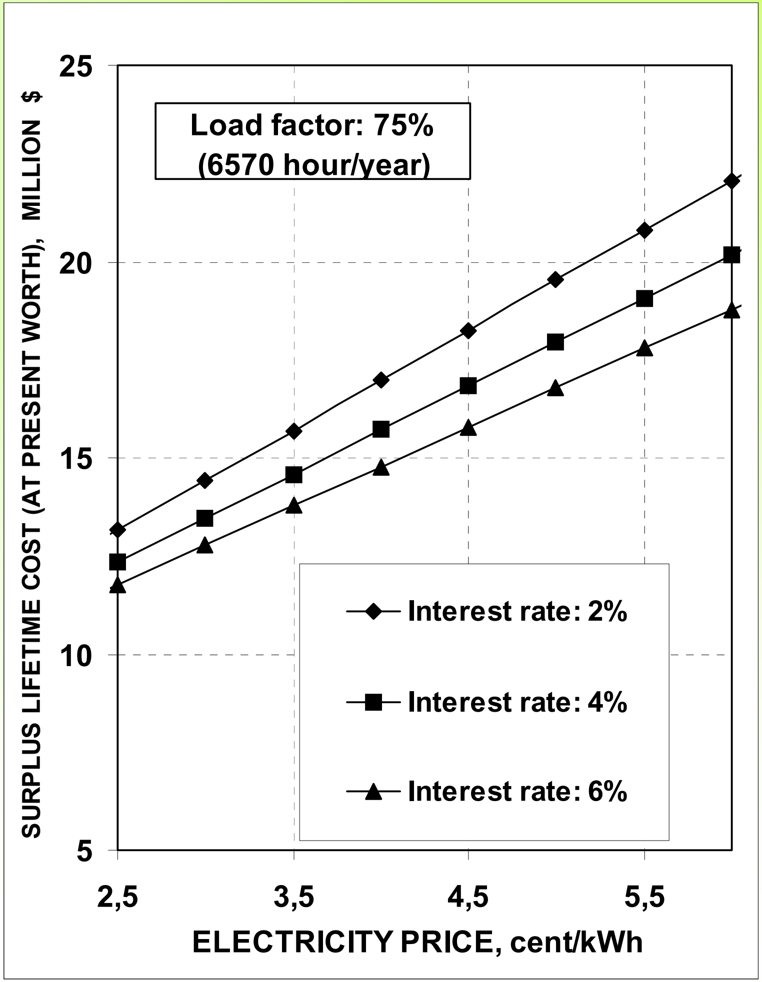
Summary Table	**HELLER System natural draft**	**Direct ACC mechanical draft**
Total cooling system related investment costs (auxiliary cooling excluded)	24.5 million US$	23.7 million US$
Surplus total life cycle cost(incl. investment) in present value	**base**	**+ 14.6 million US$**

- Therefore, at the selected project conditions (see p.36) based on the present value of the total life-cycle costs, there is as an advantage of $ 14.6 million in favor of HELLER System, what is about 60% of the complete investment cost.
- The sensitivity charts in next page (p.38) give information how the saving with the HELLER System change at different conditions than the selected one (electricity price, load factor and interest rate).

✓ *Results of the investigation – cont.*

Present Value of Surplus Life-cycle Cost of Direct ACC over HELLER System (= savings with HELLER System) as function of electricity price, load factor and interest rate





REFERENCES

[1] Bharathan, D., Hoo, E., D'Errico, P., An Assessment of the Use of Direct Contact Condensers with Wet Cooling Systems for Utility Steam Power Plants, Report by National Renewable Energy Laboratory, February 1992

[2] Lees, M., The economics of wet vs. Dry cooling for combined cycle, Seminar on Condensers and Cooling Towers for Combined Cycle, April 1994, London

[3] Szabó, Z., Improving the Economics of Water Conserving Power Plant Cooling, Journal of Power & Energy 4th quarter, 2001 - Asia Pacific Development

[4] Maulbetsch, J.S., Comparison of Alternate Cooling Technologies for California Power Plants, a PIER/EPRI report for the California Energy Commission, February 2002, Palo Alto (CA)

[5] Szabó, Z., Cool for Coal, Journal of Power & Energy 1st quarter, 2004 - Asia Pacific Development

[6] Balogh, A., Szabó, Z., The Advanced HELLER System – Technical Features & Characteristics, EPRI Conference on Advanced Cooling Strategies/Technologies, June 2005, Sacramento (CA)